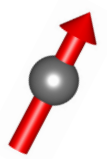
Landau levels and quantum oscillations

Fermi surface determination

David Shoenberg

Shubnikov and de Haas



by Alexander Tsirlin, Leipzig University

Lecture 25: January 25, 2024

Person

David Shoenberg

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1911–2004

- early 1930's: studied physics at Trinity College, Cambridge
- 1932-1934: student of Peter Kapitza, first helium liquefier
- 1930s: magnetoresistance measurements observation of *quantum oscillations*
- since 1944: lecturer and later professor at Cambridge
- 1940's: experiments on superconductors (penetration depth)
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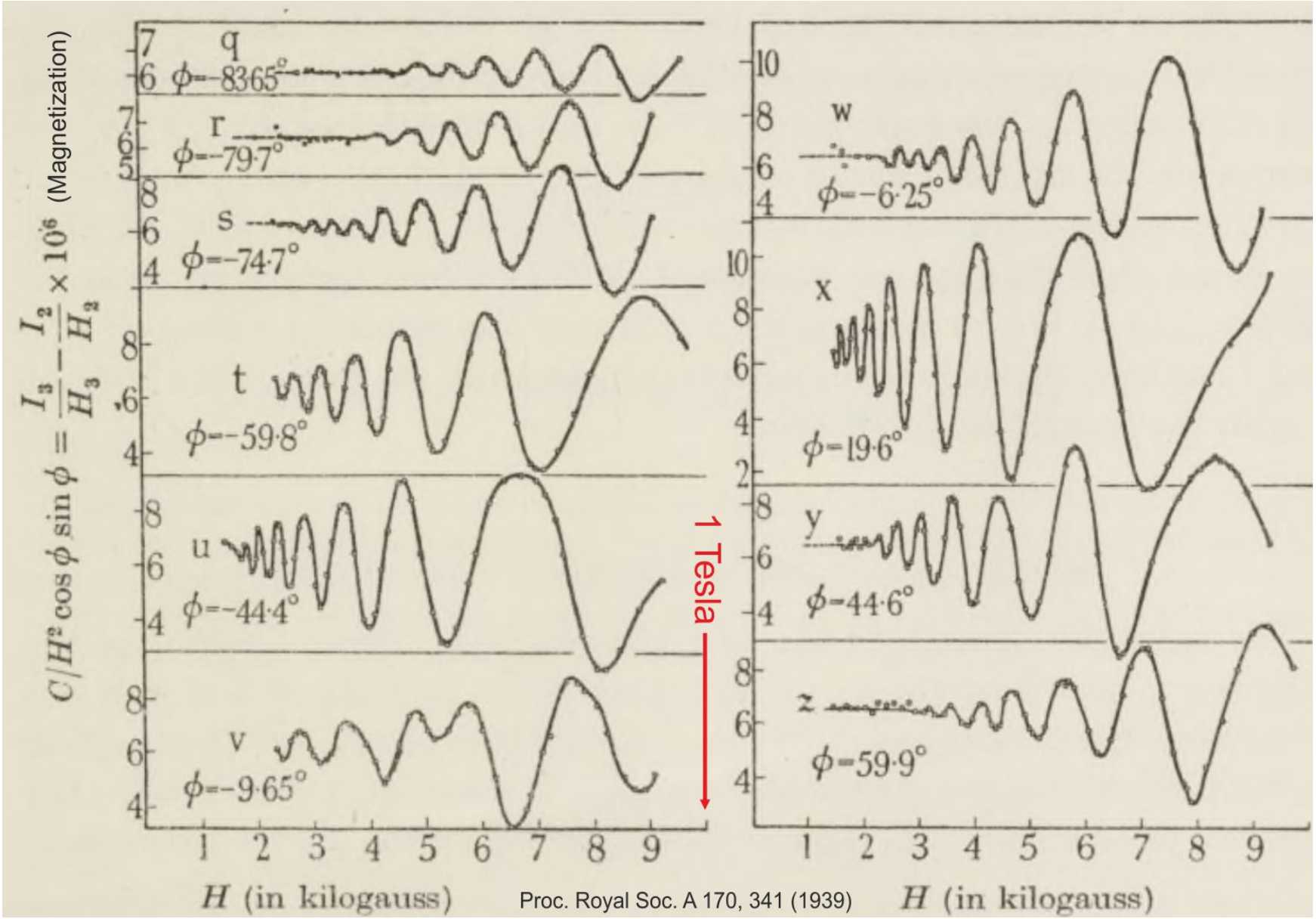
DAVID SHOENBERG

FORTY ODD YEARS IN THE COLD

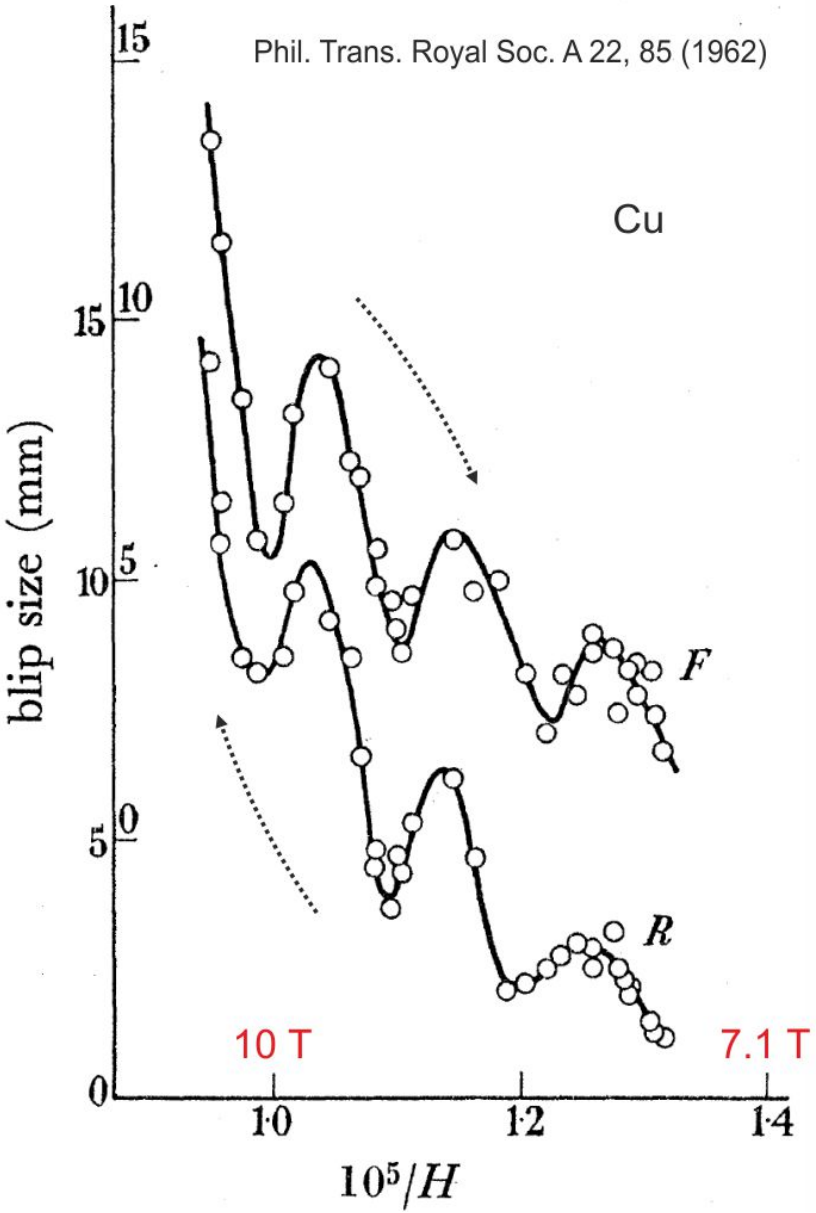
reminiscences of work in low temperature physics

Oscillations in Bi



Proc. Royal Soc. A 170, 341 (1939)

Oscillations in Cu



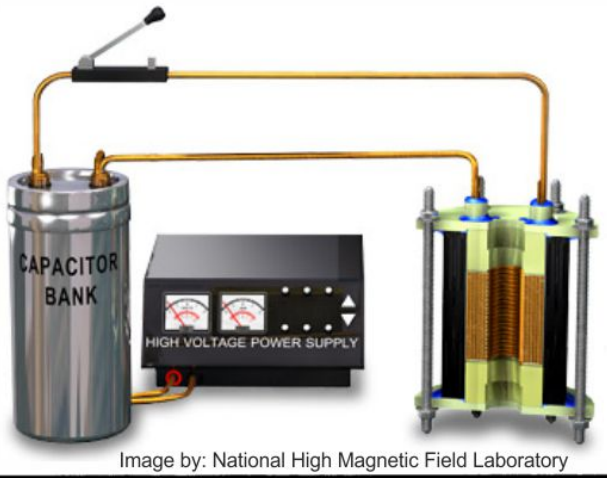
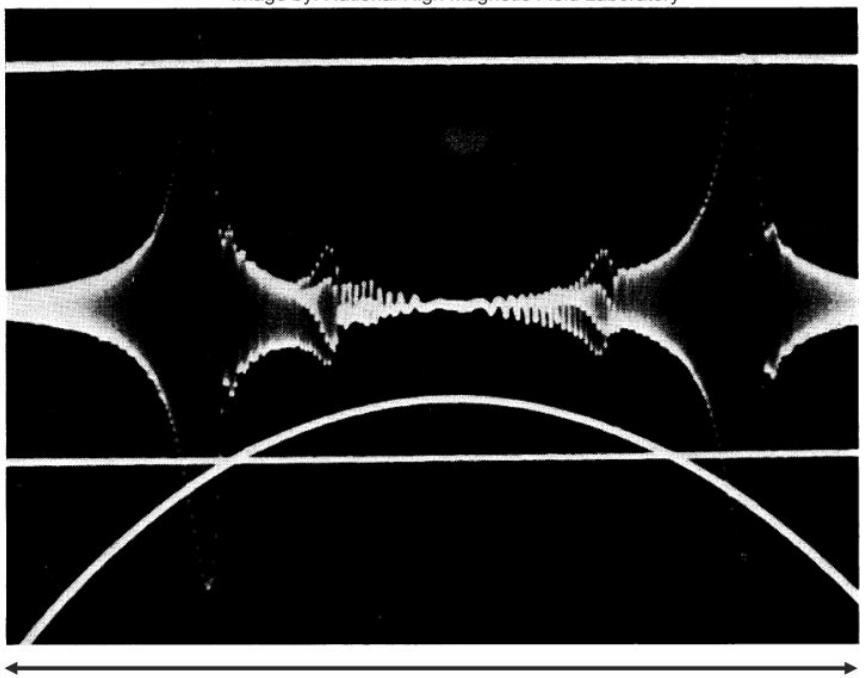
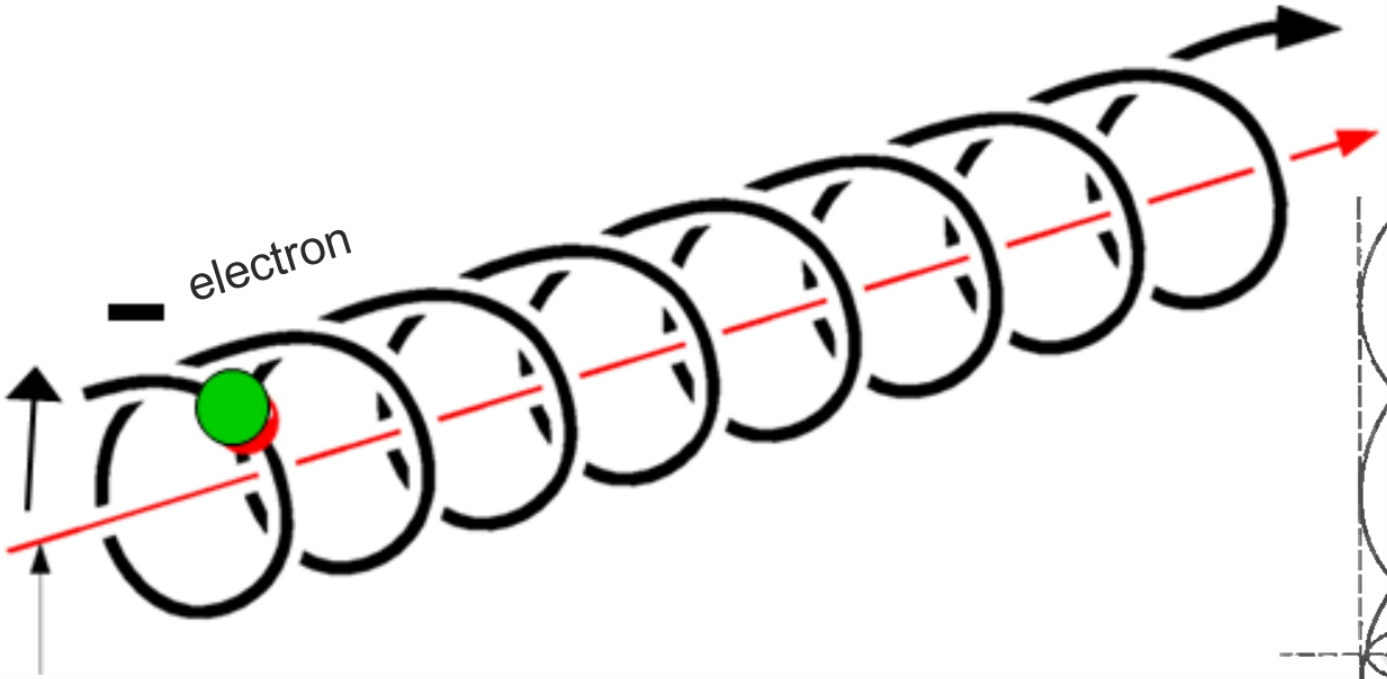
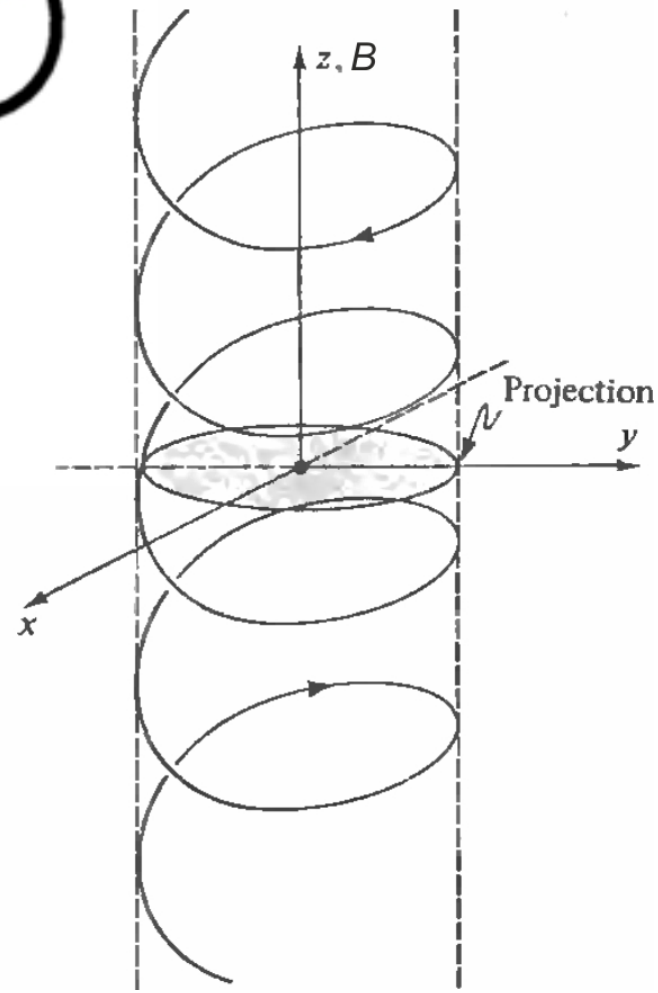


Image by: National High Magnetic Field Laboratory



Cyclotron motion



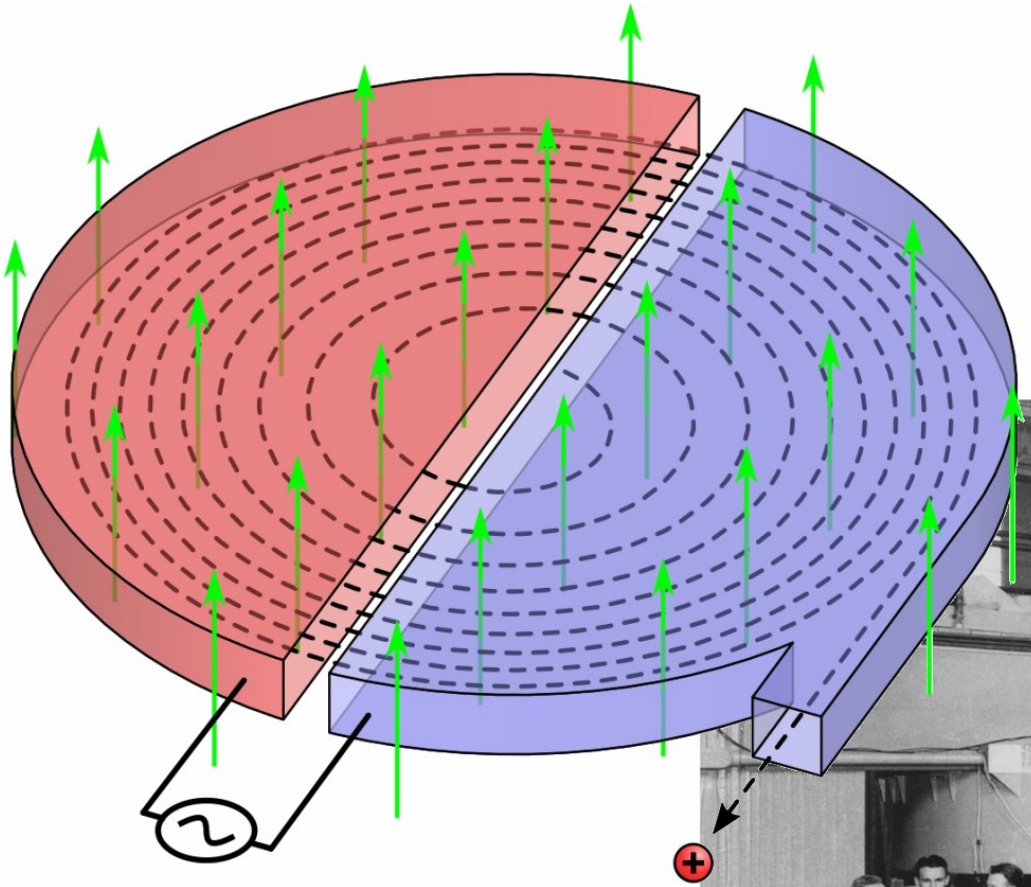


Periodic motion
in the plane perpendicular to the field

Ashcroft and Mermin, Solid State Physics; Matthias W Hirsch (CC-BY-SA)

Cyclotron

acceleration of charged particles



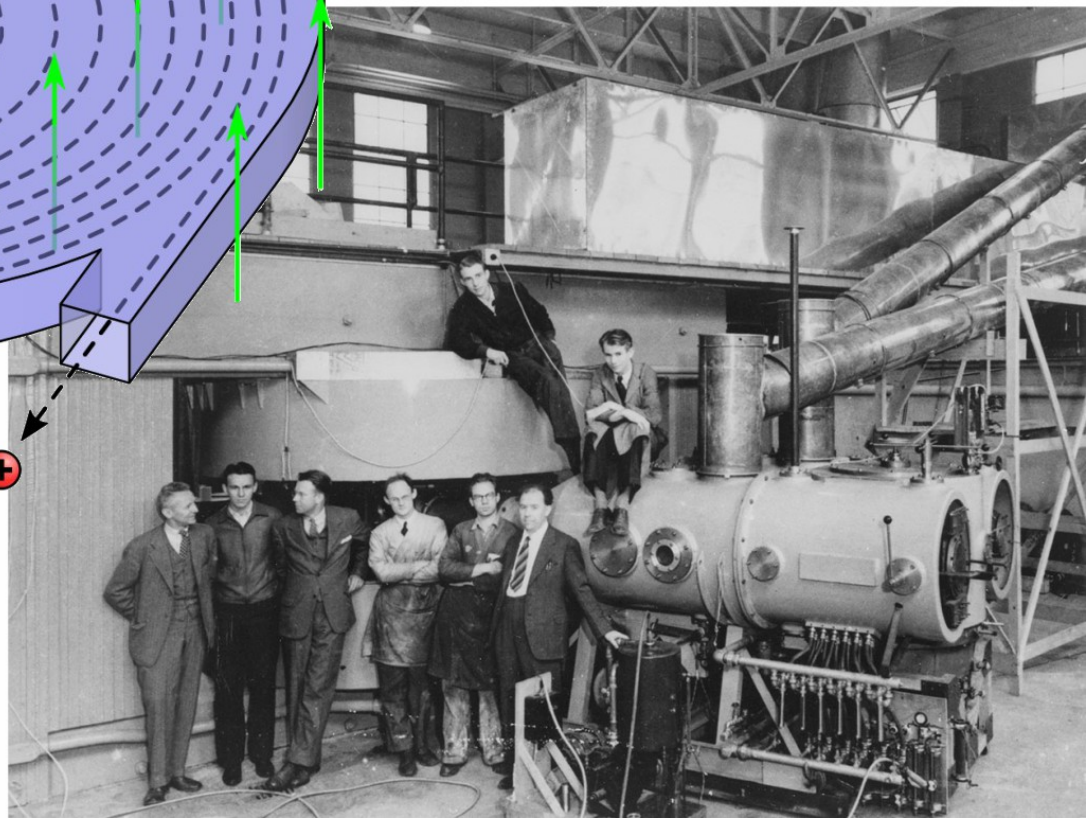
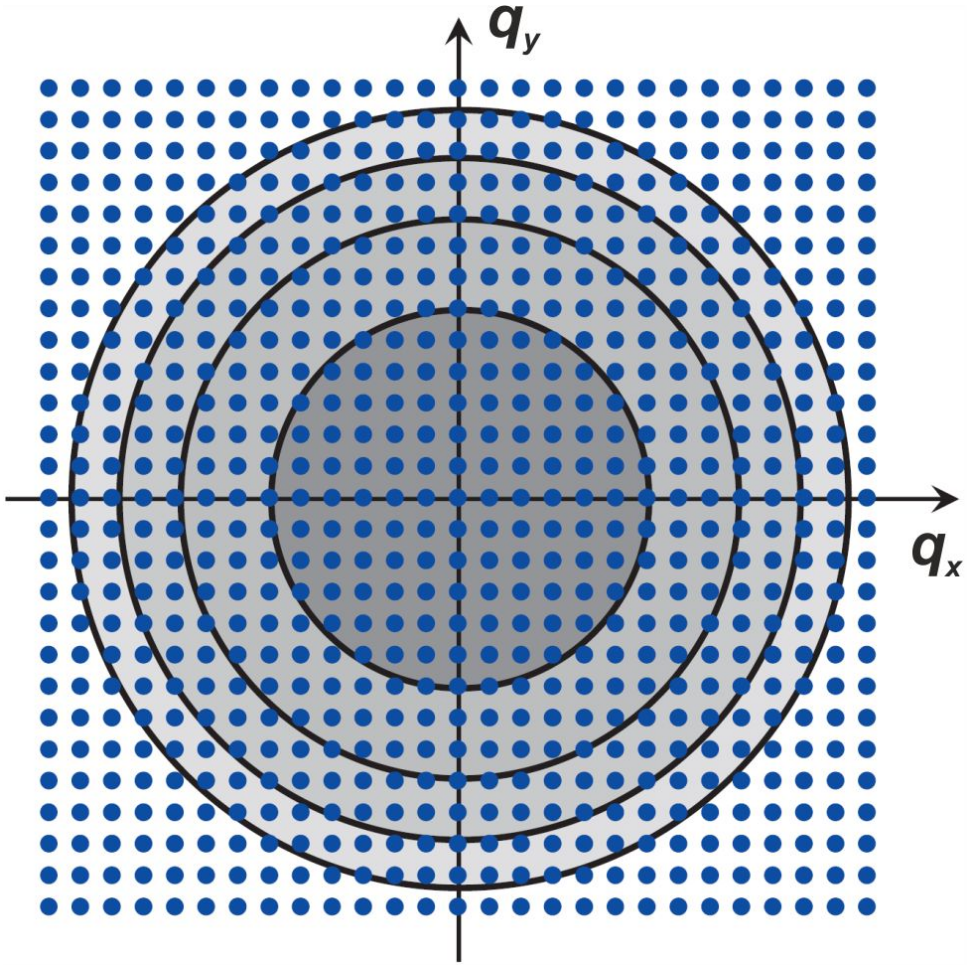
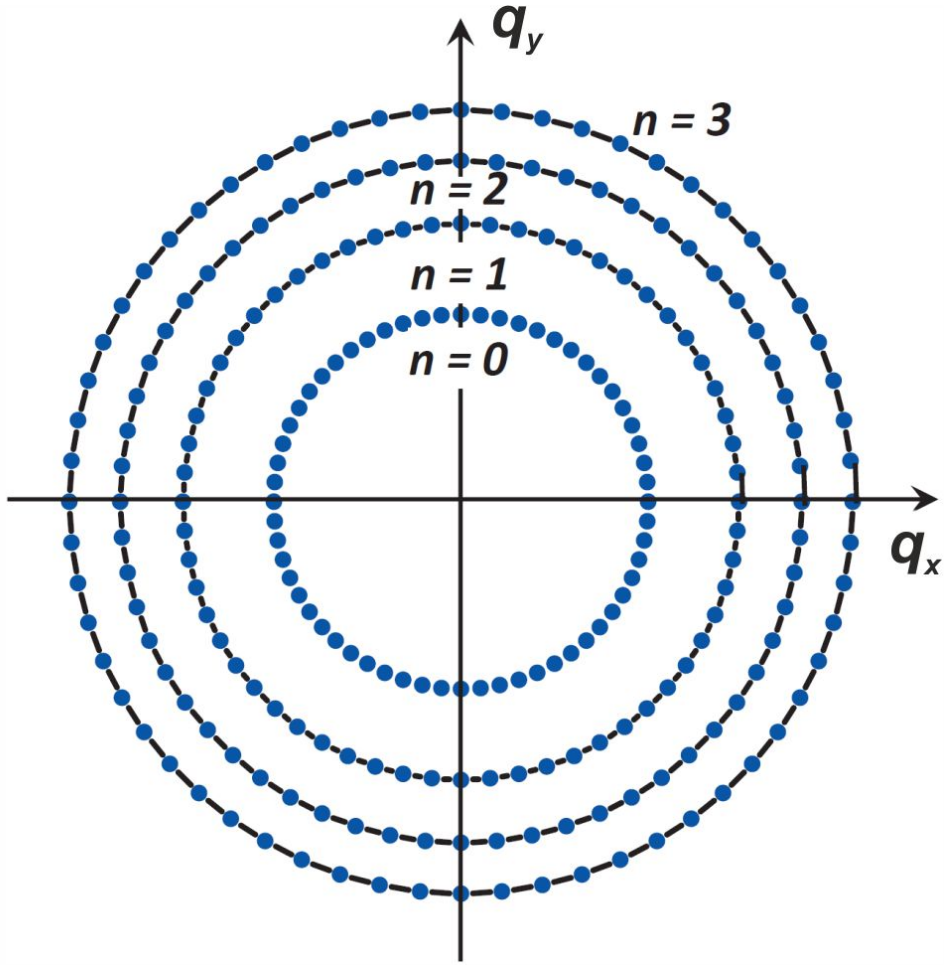


Image credits: MikeRun,
Science Museum London (CC-BY-SA)

zero field ($B = 0$)



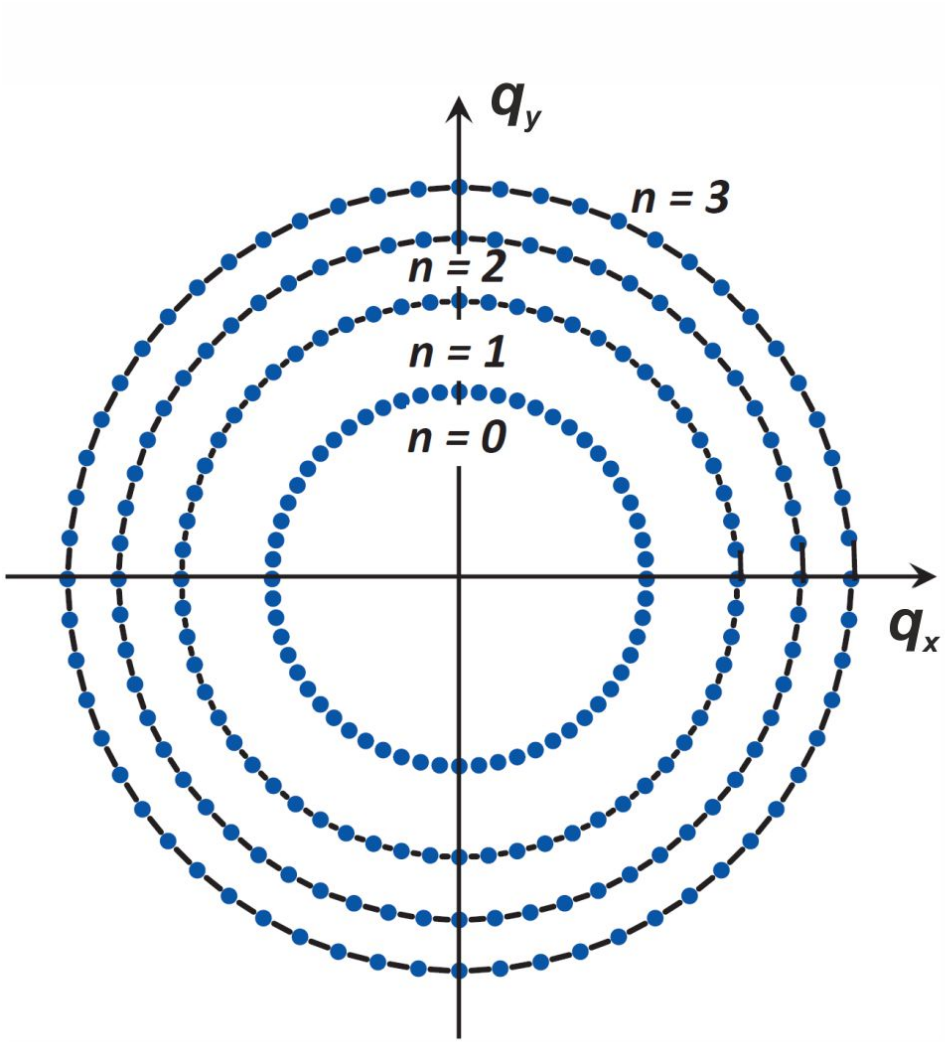
magnetic field ($B \neq 0$)

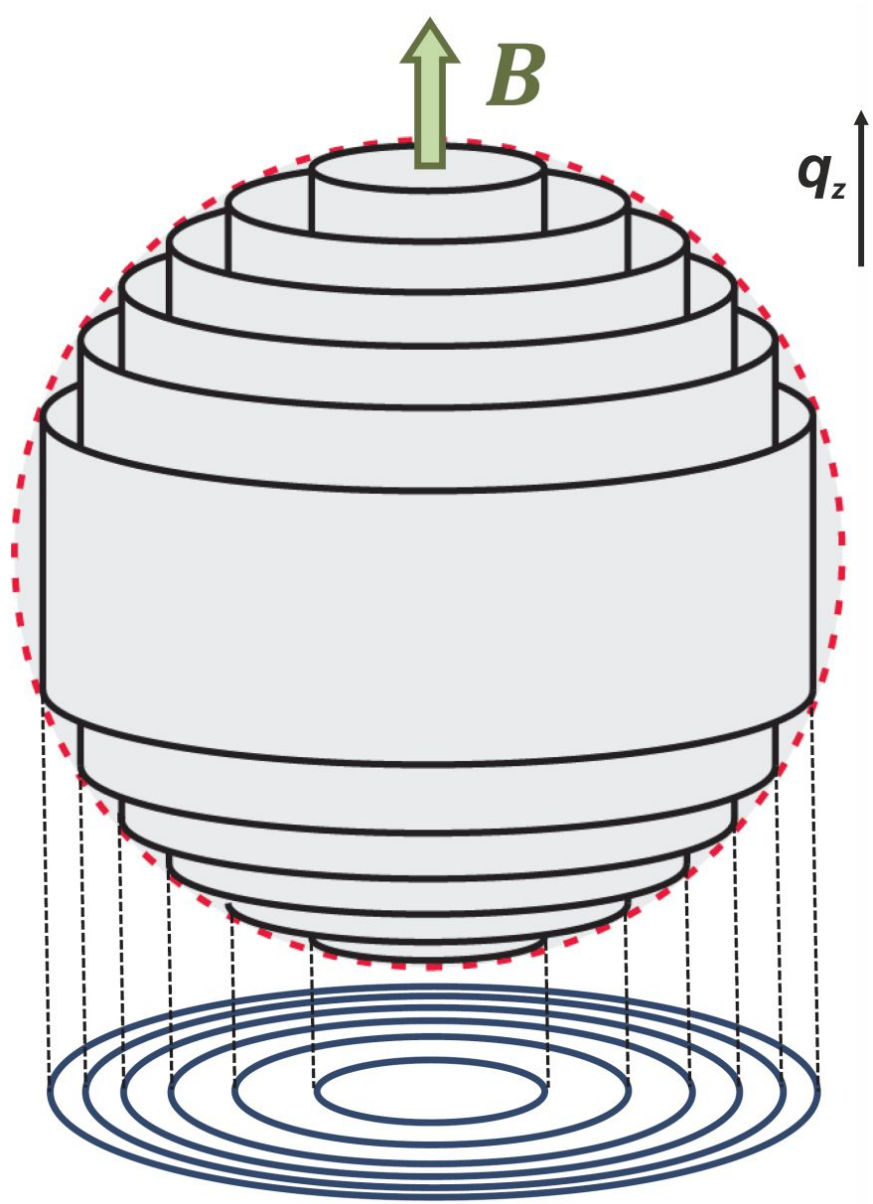


Magnetic field re-distributes electronic states of a crystal

Gross and Marx, Festkörperphysik

Landau levels





Gross and Marx, Festkörperphysik

Person

Shubnikov and de Haas

Wander Johannes de Haas
1878–1960

- 1895: started paralegal studies
- from 1900: physics studies in Leiden
- 1910: married Hendrik Lorentz's daughter
- 1912: PhD in physics
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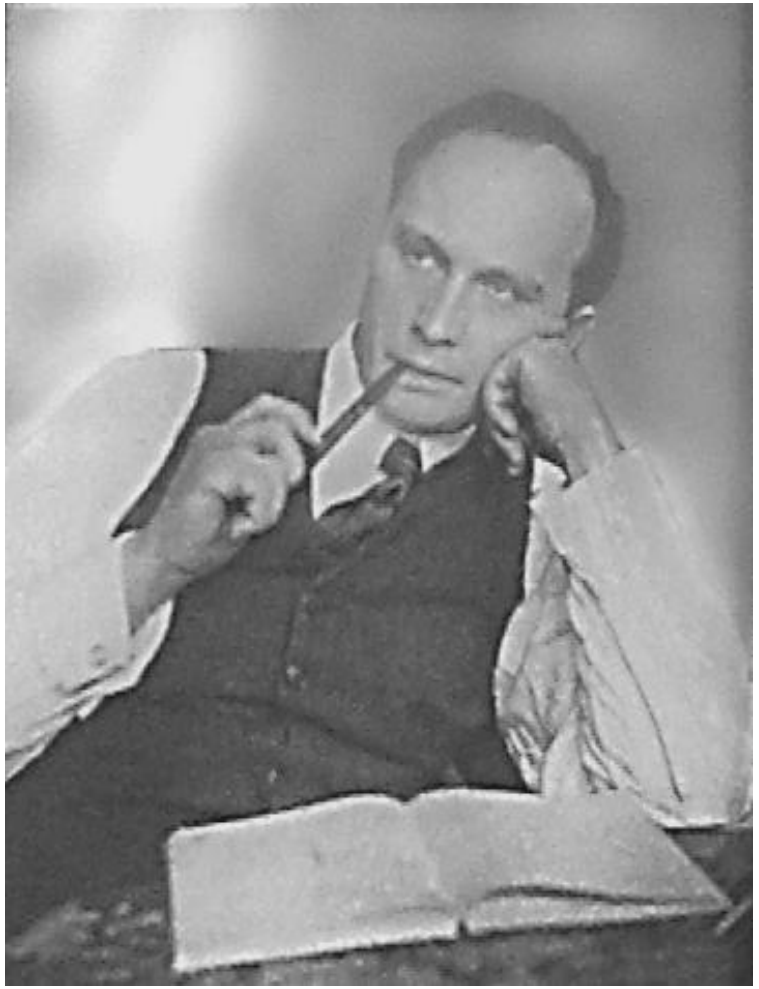
- conservator in the museum in Haarlem
- from 1925: professor of physics in Leiden, successor of Kamerlingh Onnes

Best low-temperature lab of that time

- 1918: started physics studies in Saint Petersburg
- 1924–26: new method for **growing high-quality single crystals** of metals
- 1926–30: visiting researcher in de Haas' lab
- 1930: Shubnikov – de Haas effect



Lev Shubnikov
1901–1937

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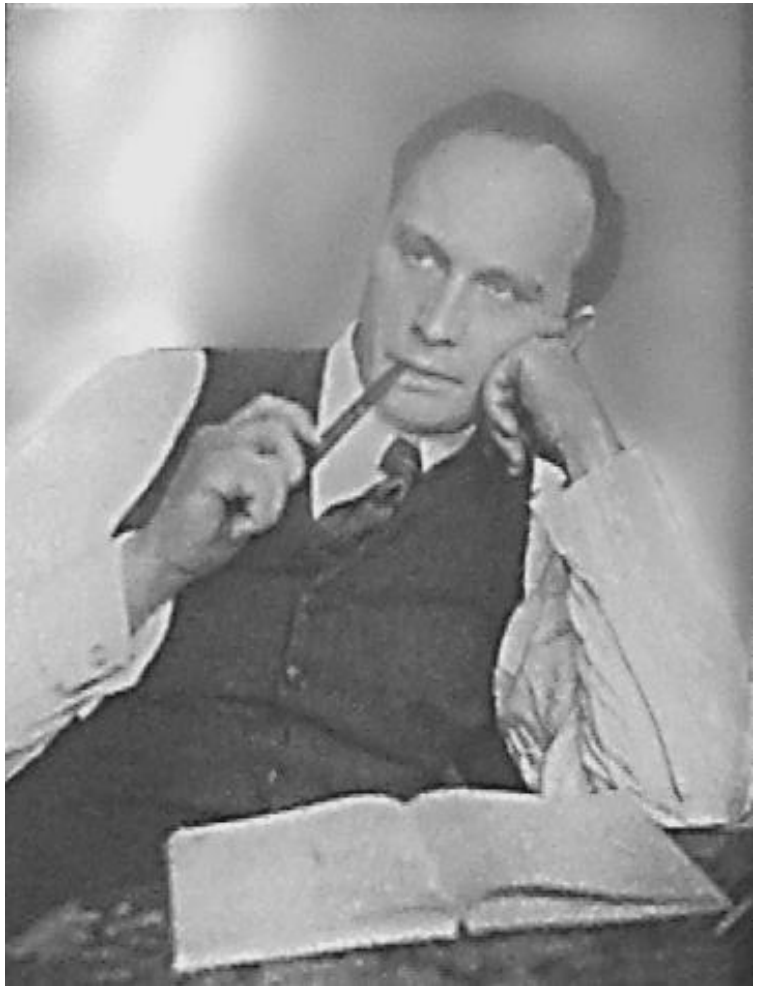
- 1931–37: head of low-T lab in Kharkiv, Ukraine
- Landau becomes head of theory department in the same institute

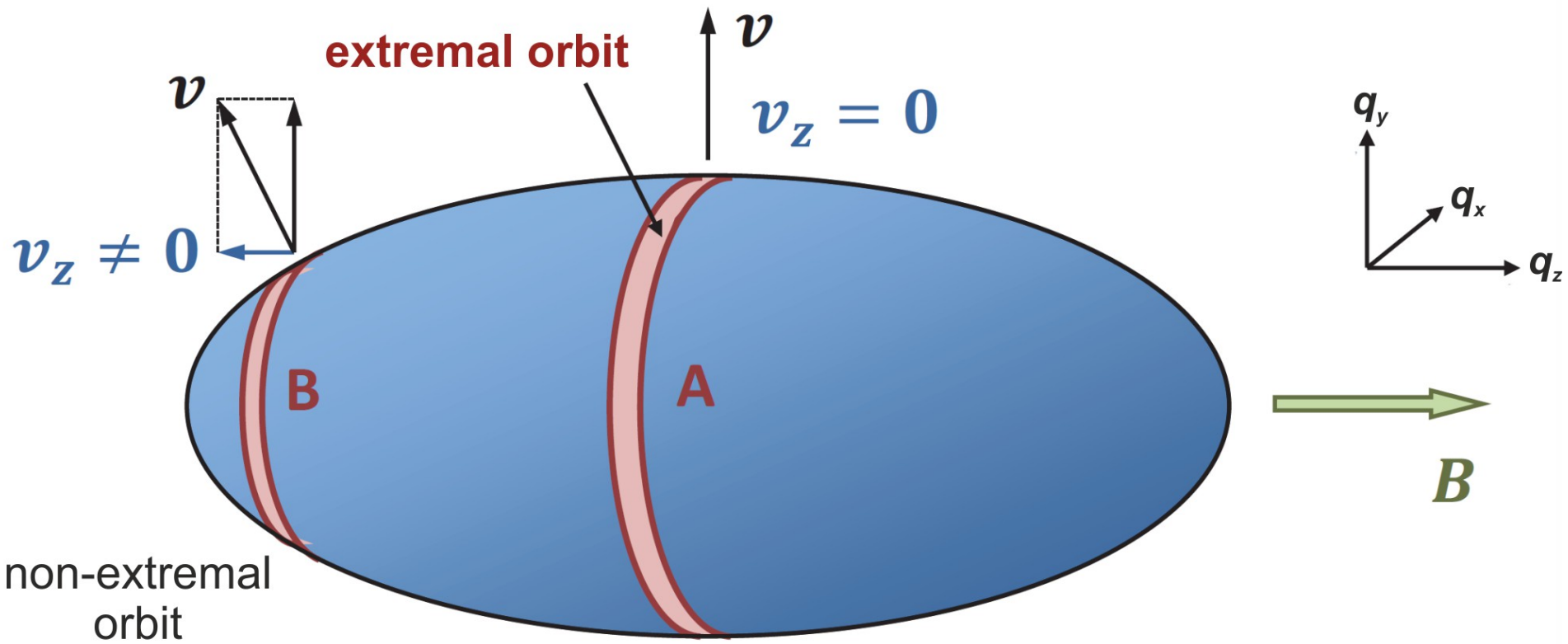
Landau levels



Lev Shubnikov
1901–1937

Experimental technique

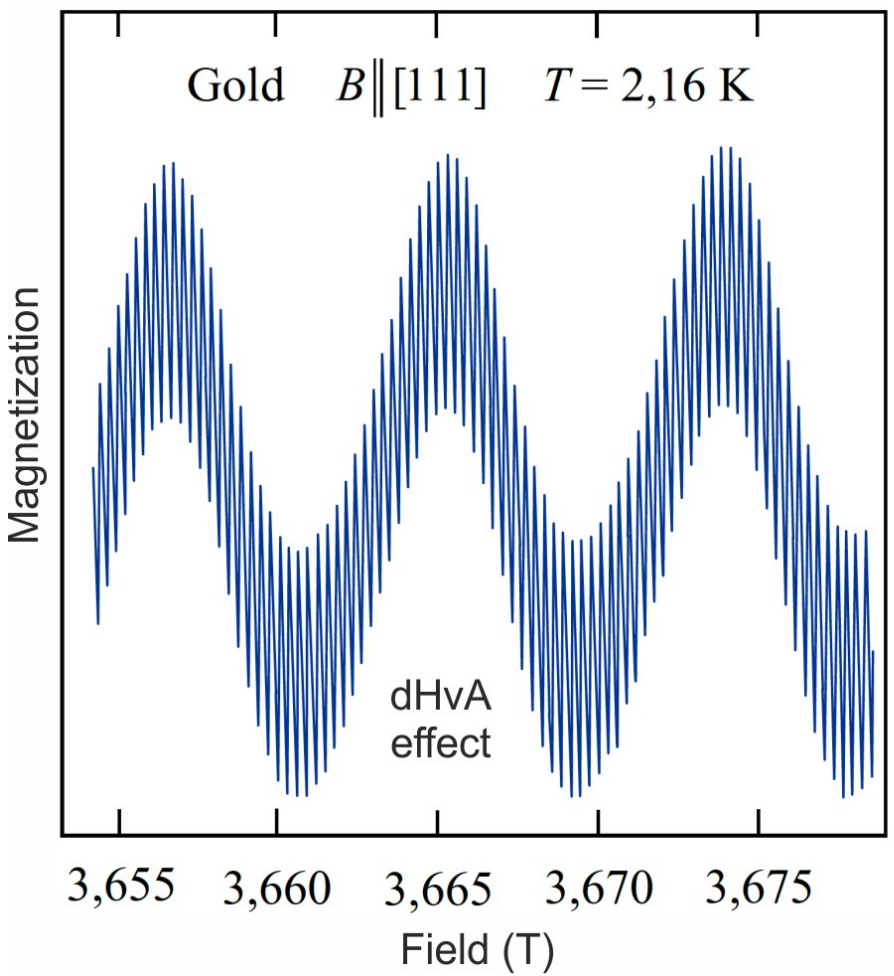
Fermi surface determination

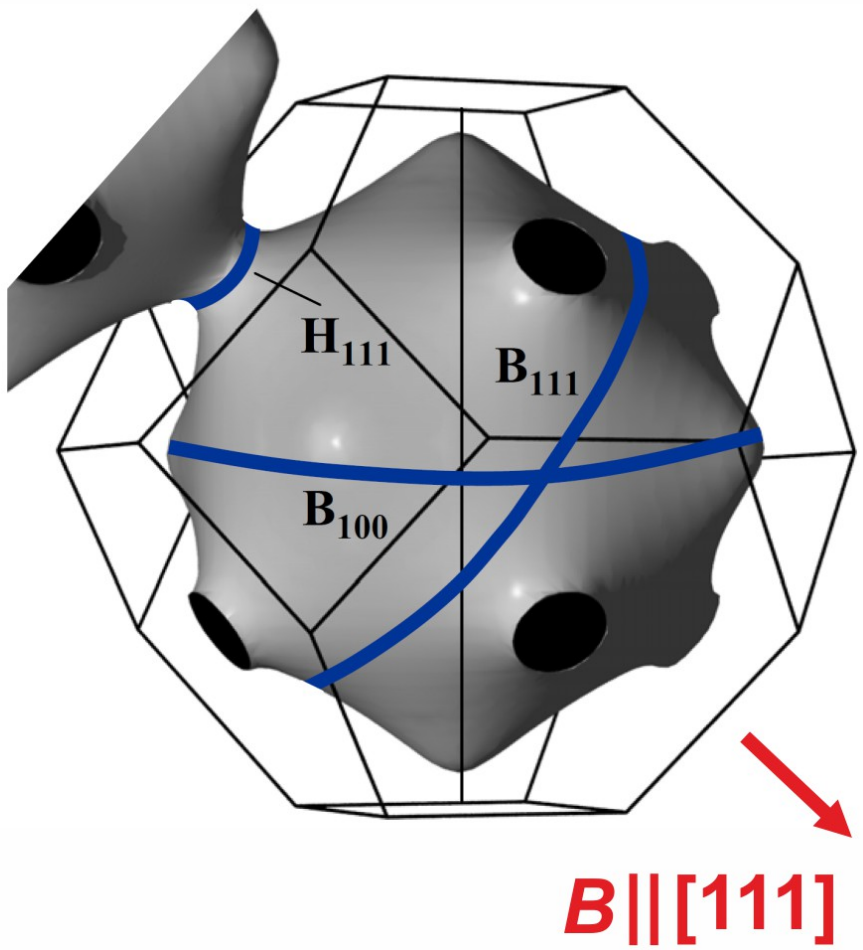


Only **extremal orbits** manifest themselves in quantum oscillations

Gross and Marx, Festkörperphysik

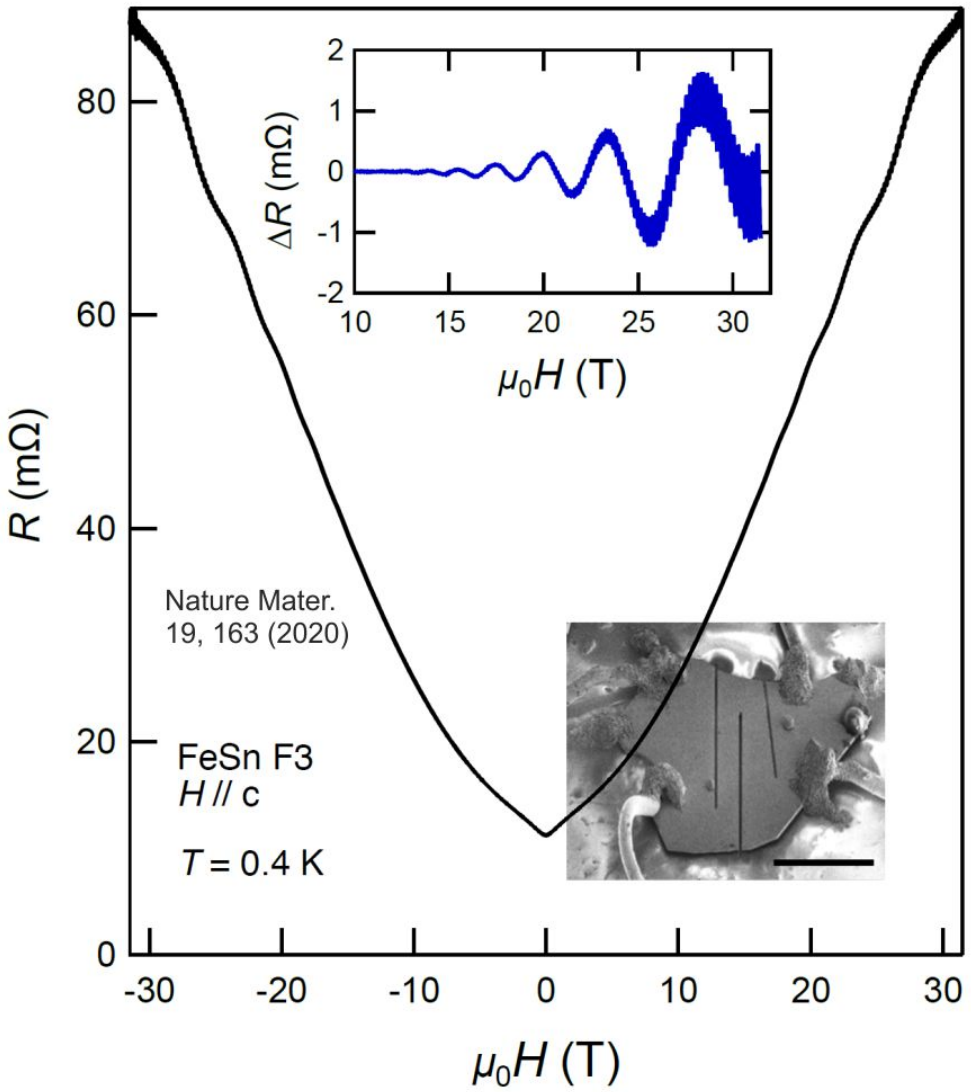
Probe of the Fermi surface

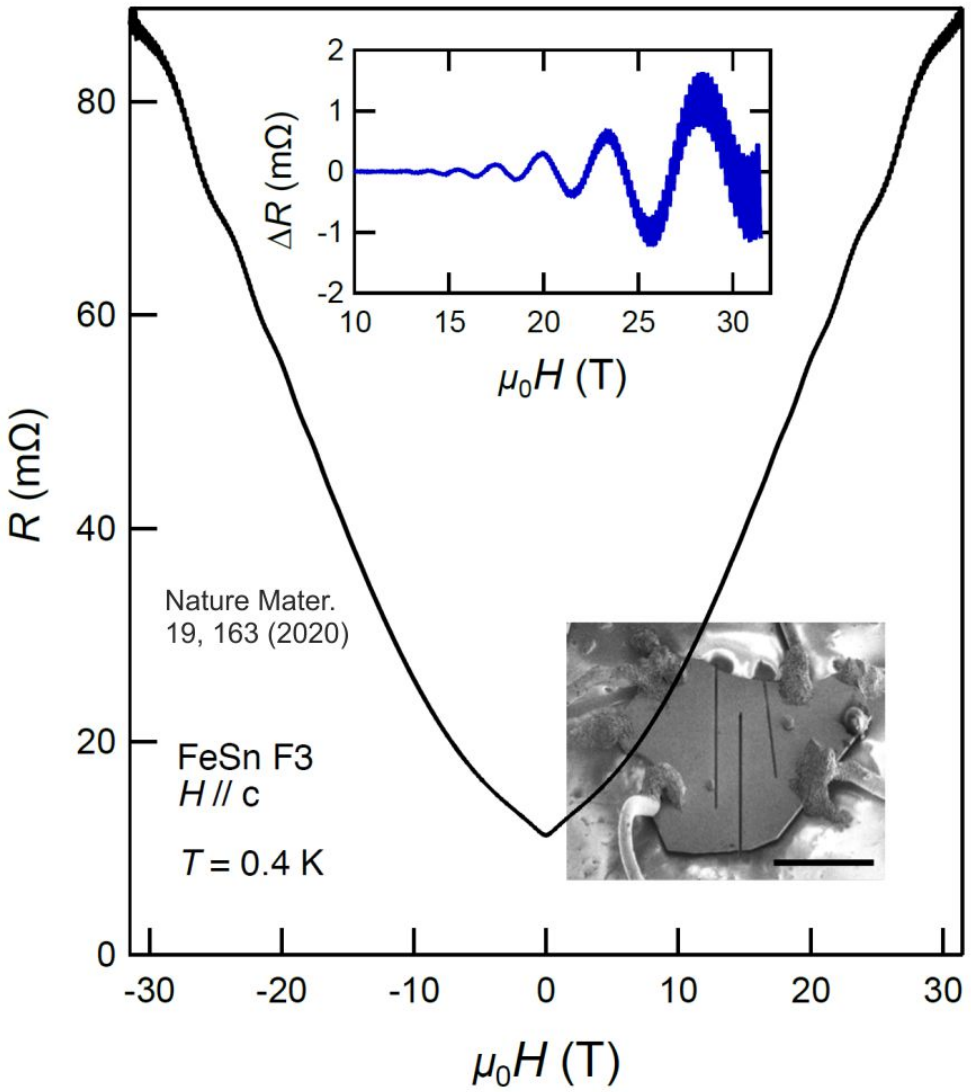




Two frequencies from two extremal cross-sections: “belly” and “neck”

Hunklinger, Festkörperphysik


R (mΩ)
80
60
40
20
0
-30
-20
-10
0
10
20
30
μ0H (T)
ΔR (mΩ)
2
1
0
-1
-2
10
15
20
25
30
μ0H (T)
Nature Mater.
19, 163 (2020)
FeSn F3
H // c
T = 0.4 K


R (mΩ)
μ0H (T)
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Nature Mater.
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FeSn F3
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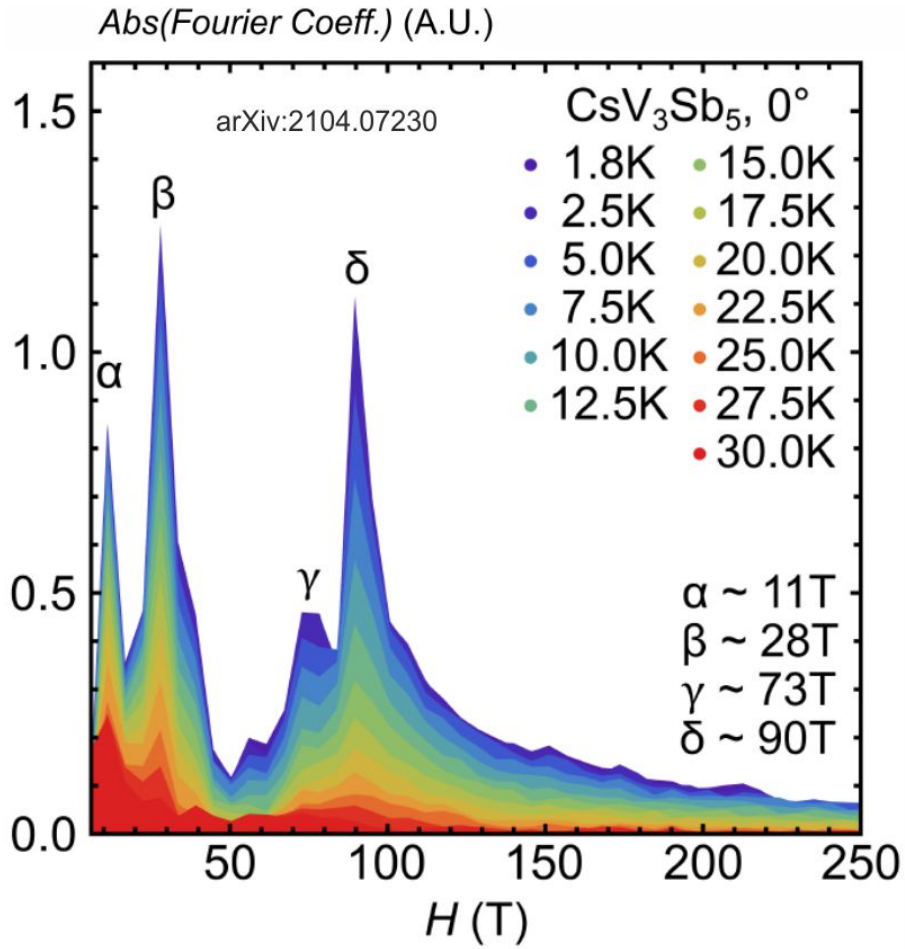
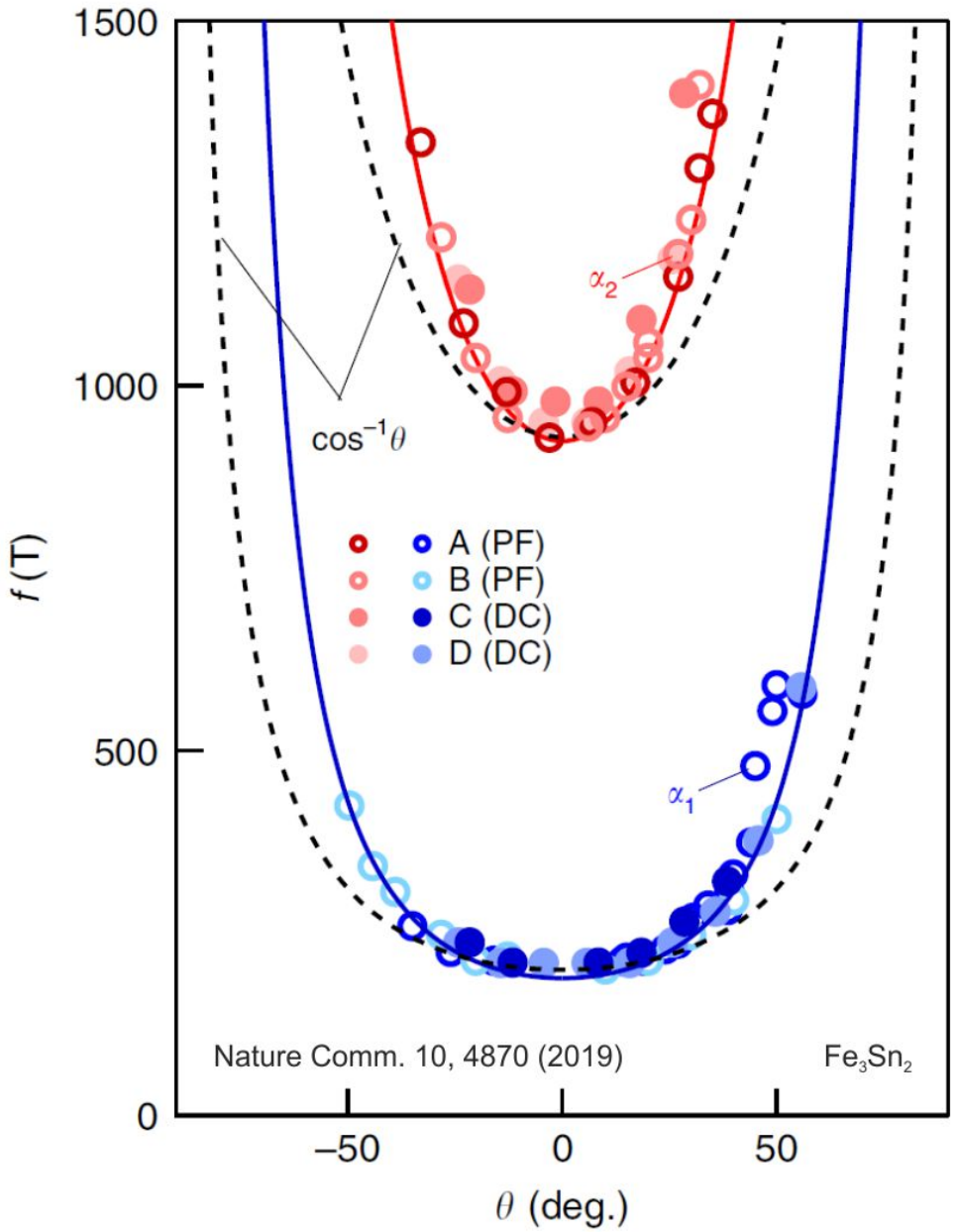
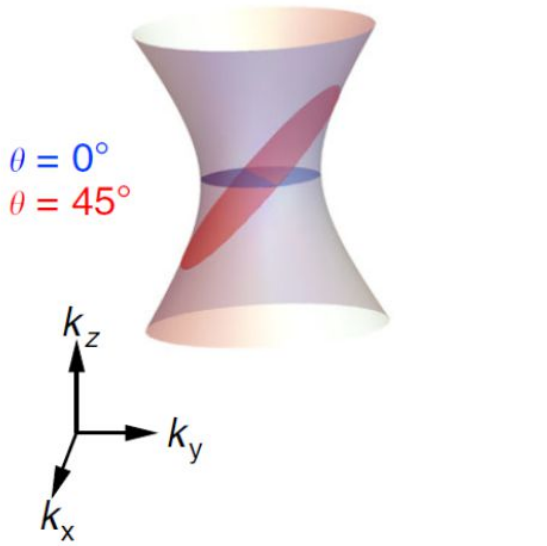
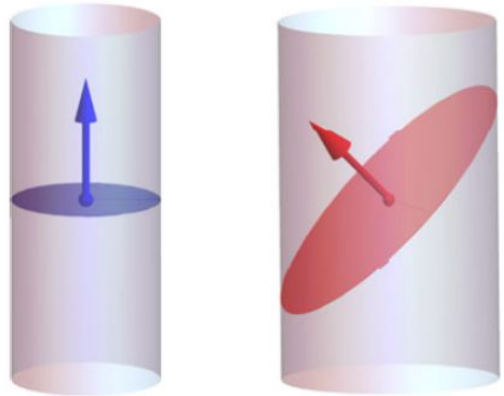
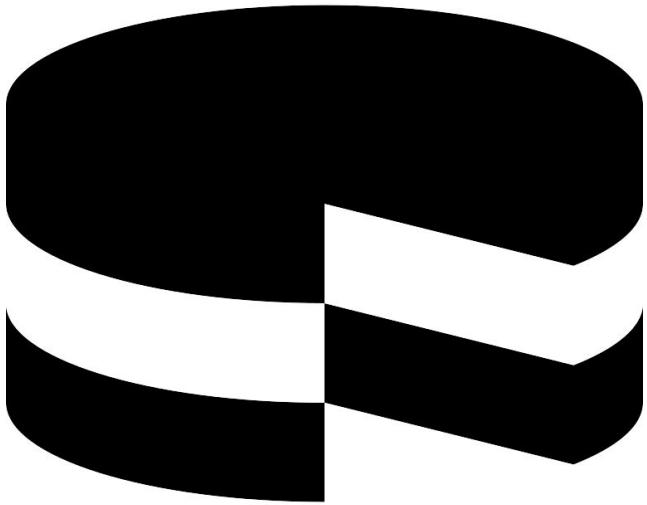

Abs(Fourier Coeff.) (A.U.)
arXiv:2104.07230
CsV3Sb5, 0°
1.8K
2.5K
5.0K
7.5K
10.0K
12.5K
15.0K
17.5K
20.0K
22.5K
25.0K
27.5K
30.0K
α
β
γ
δ
α ~ 11T
β ~ 28T
γ ~ 73T
δ ~ 90T
H (T)

Angular dependence

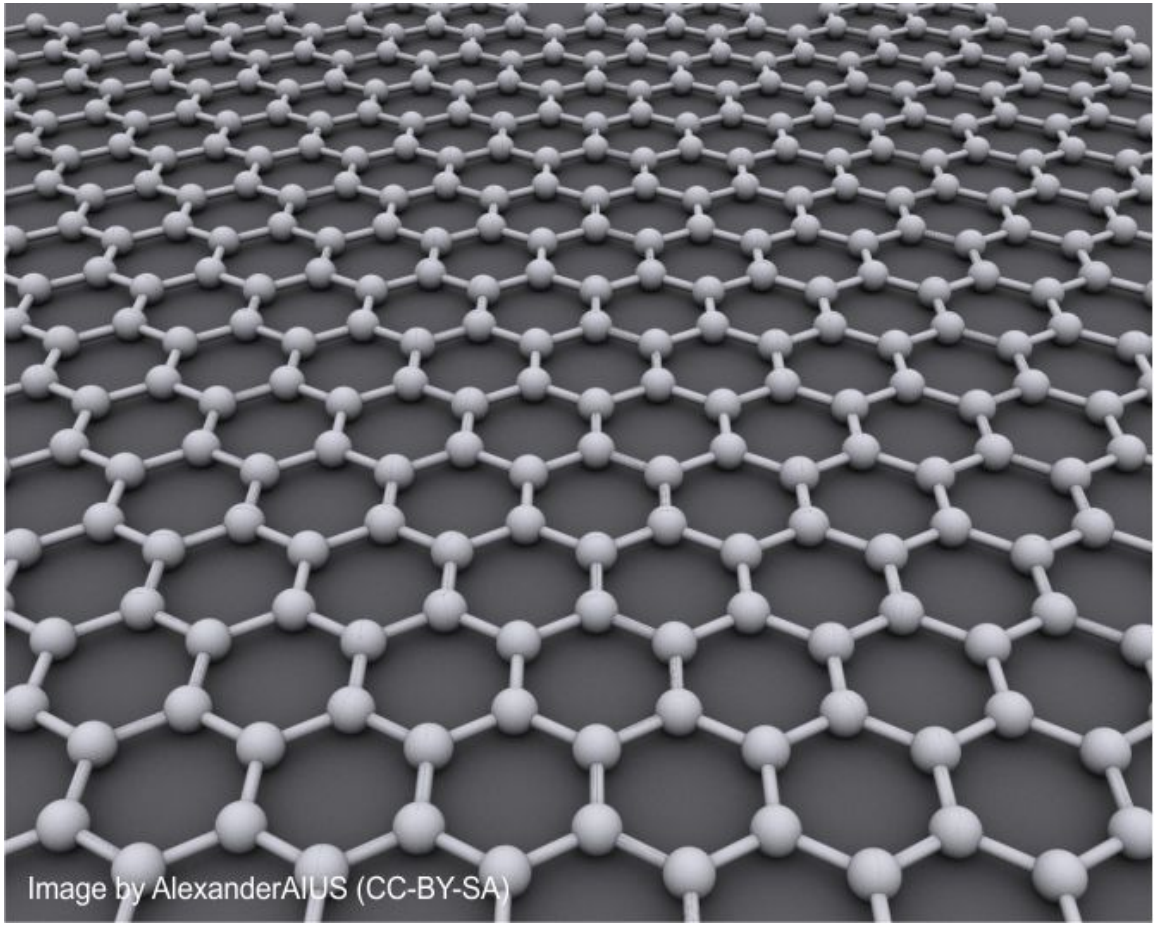








Material

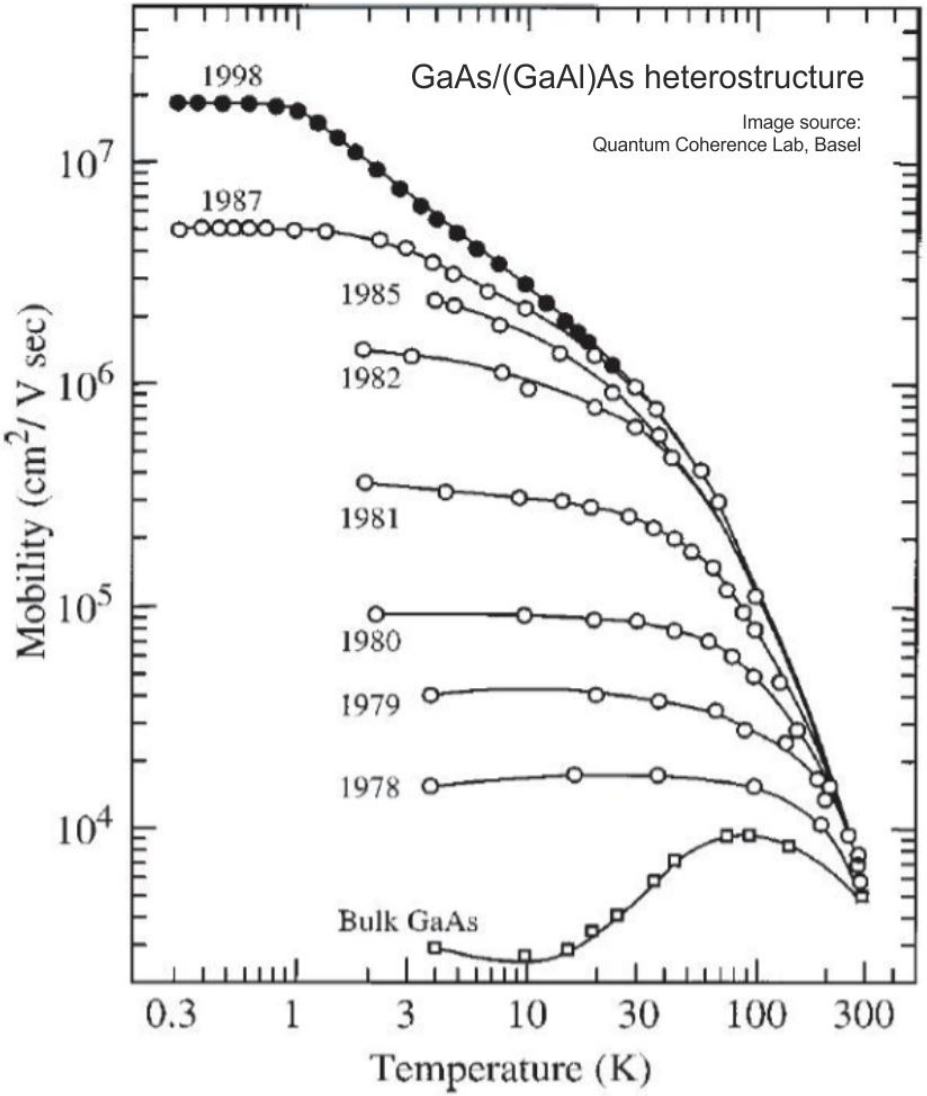


Graphene

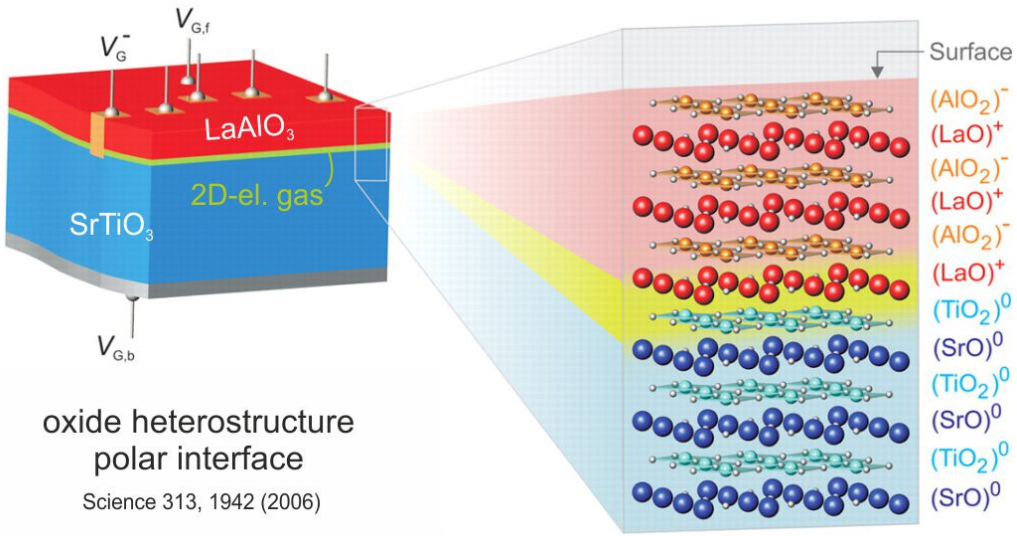
$\mu \sim 10^4\,\mathrm{cm}^2/\mathrm{V{\cdot}s}$

(at 300 K)

semiconductor heterostructure

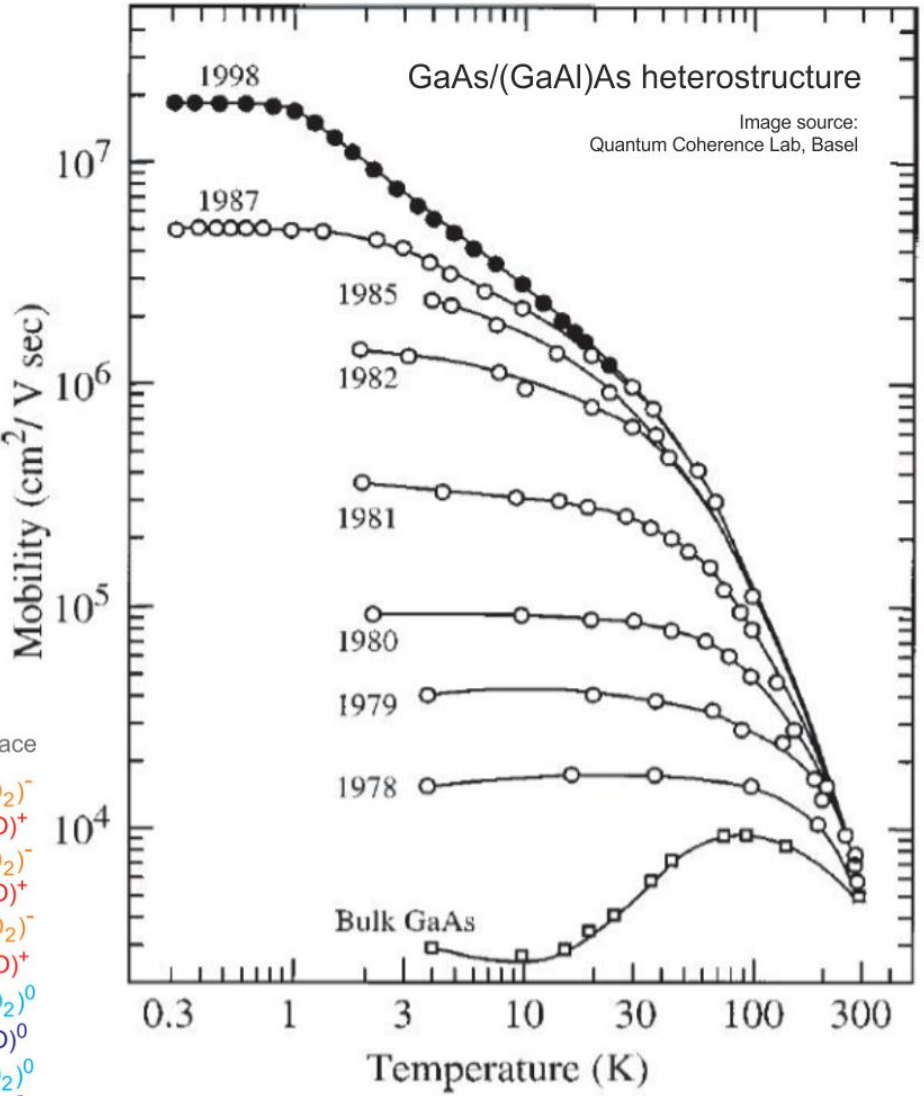


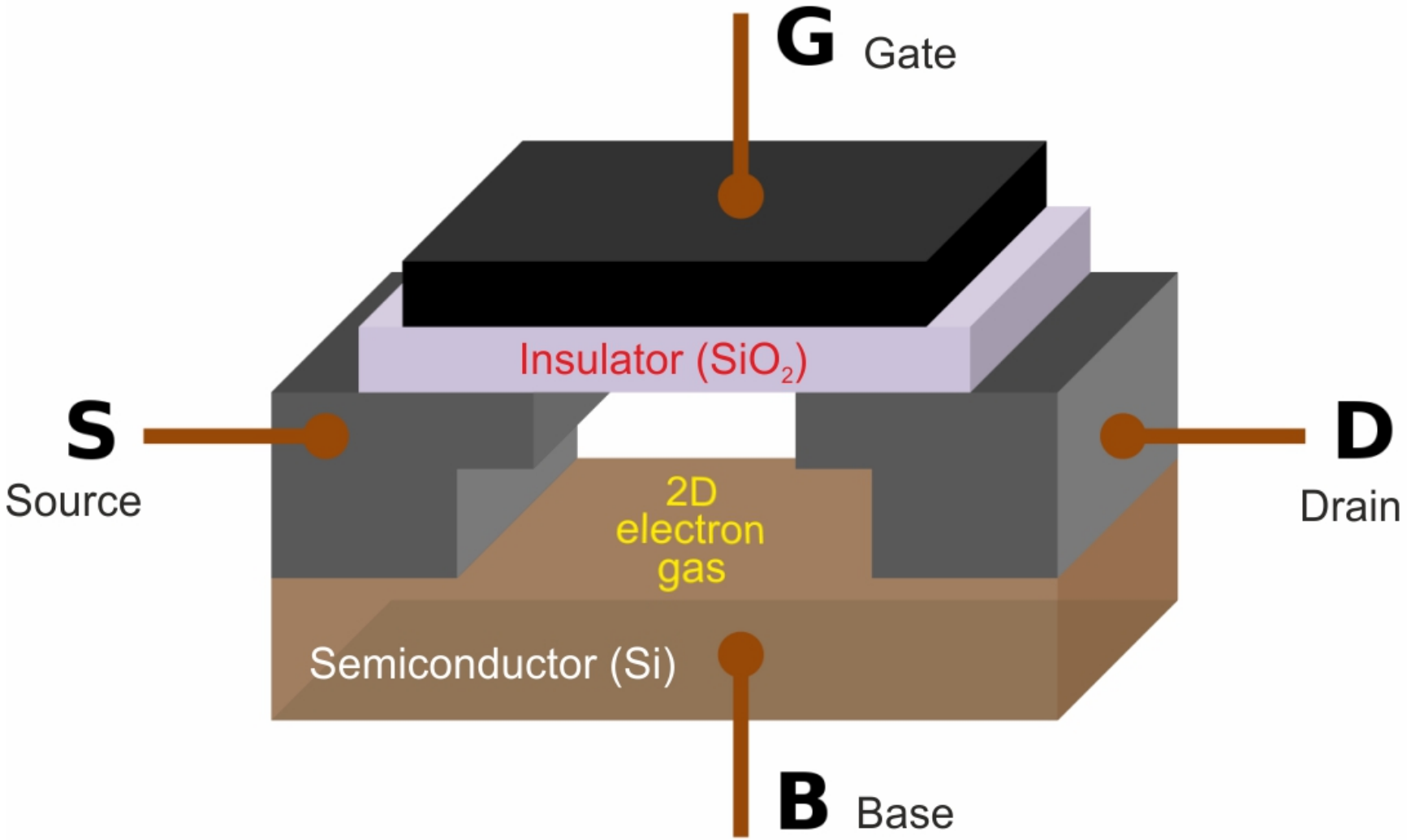
semiconductor heterostructure



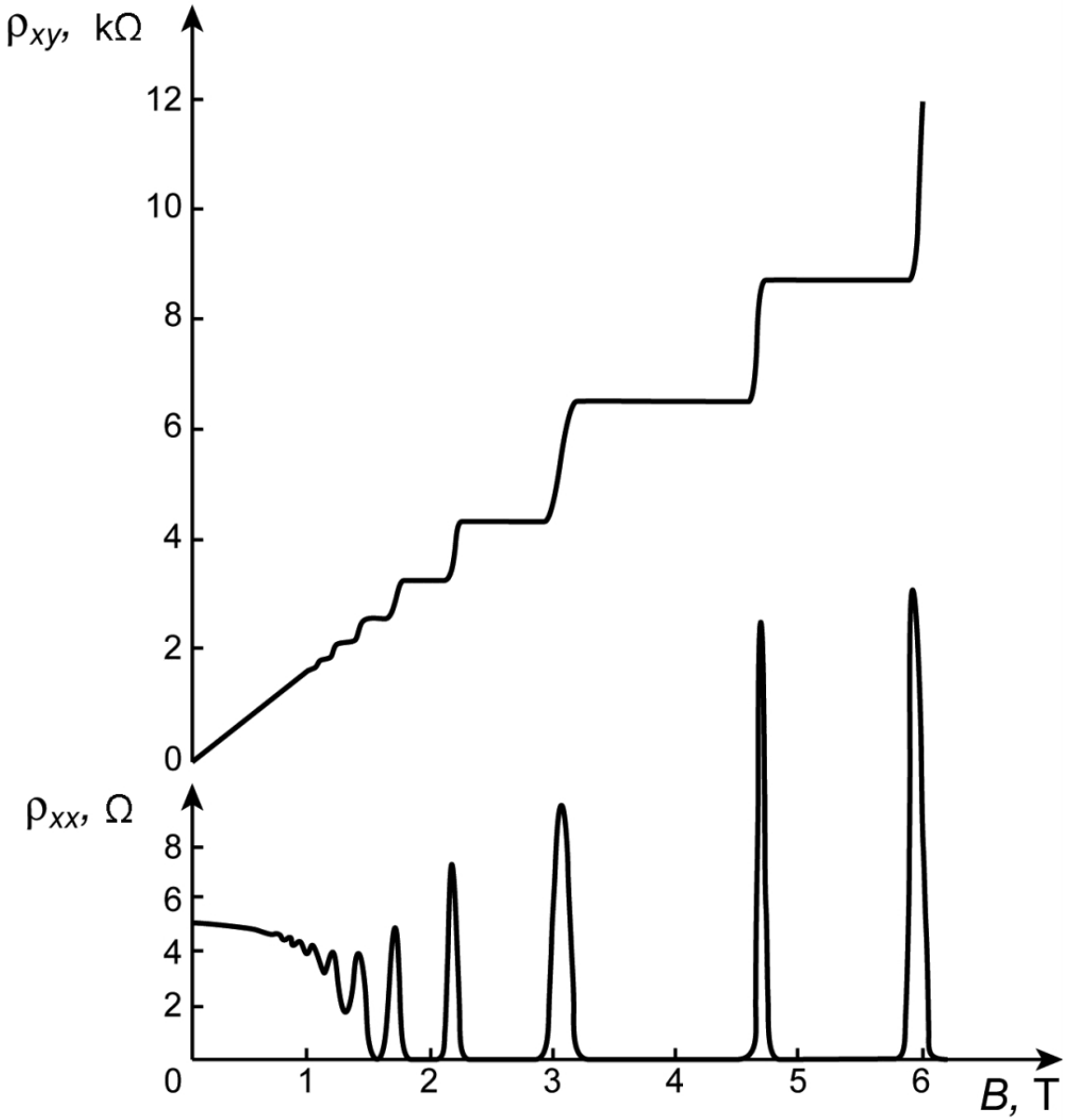
oxide heterostructure
polar interface

Science 313, 1942 (2006)





MOSFET = Metal-Oxide-Semiconductor Field-Effect Transistor



$$R_{xy} = \frac{h}{e^2 \nu}$$

ν integer or fractional

$$R_K = \frac{h}{e^2} \simeq 25812.807\,\Omega$$

von Klitzing constant